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# **The Effect of Dietary Changes on Distinct Components of Metabolic Syndrome in a Young Sri Lankan Population at High-Risk of Cardiovascular Disease**

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## Abstract

South Asian populations are predisposed to early onset of metabolic syndrome. Lifestyle intervention programs have demonstrated a reduction in metabolic syndrome and CVD risk; however the most effective components of the multi-faceted lifestyle interventions are unknown. We studied 2637 Sri Lankan males (n=1237) and females (n=1380), with a mean BMI:  $23.9 \pm 4.2 \text{ kg/m}^2$ , age  $22.5 \pm 10.0$  years who had participated in a 5-year lifestyle modification program to examine the effect of dietary changes on distinct components of the metabolic syndrome. The dietary intervention comprised advice to replace polished starches with unpolished; high-fat meat and dairy with low-fat; and high-sugar beverages and snacks with low-sugar varieties. For the purposes of this analysis, data from the control and intensive lifestyle groups were combined. Anthropometric and biochemical data were recorded and a food frequency questionnaire completed annually. Multiple regression was used to determine the effect of the dietary changes on distinct components of the metabolic syndrome. The ratio unpolished:polished rice was inversely related to change in fasting glucose ( $\beta=-0.084$ ,  $P=0.007$ ) and triglycerides ( $\beta=-0.084$ ,  $P=0.005$ ), and positively associated with change in HDL-cholesterol ( $\beta=0.066$ ,  $P=0.031$ ) at the 5 year follow-up after controlling for relevant confounders. Red meat intake was positively associated with fasting glucose concentrations ( $\beta=0.05$ ,  $P=0.017$ ), while low-fat ( $\beta=-0.046$ ,  $P=0.018$ ) but not high-fat dairy ( $\beta=0.003$ ,  $P=0.853$ ) was inversely related to glucose tolerance at the follow-up visit. Replacement of polished with unpolished rice may be particularly effective dietary advice in this and similar populations.

## Abbreviations

BMI: body mass index

CVD: cardiovascular disease

FPG: fasting plasma glucose;

HDL: high-density lipoprotein

LDL: low-density lipoprotein

MetS: metabolic syndrome

MUFA: monounsaturated fat

PUFA: polyunsaturated fat

SFA: saturated fat

TG: triglycerides

T2DM: type 2 diabetes

WC: waist circumference

2hPG: 2-hour plasma glucose

### **Trial registration**

The trial is registered with the World Health Organisation and Sri-Lanka clinical trial registry number SLCTR/2008/003

## Introduction

The metabolic syndrome (MetS) constitutes a cluster of cardiovascular risk factors, which double the risk for coronary heart disease and increase the risk for type 2 diabetes (T2DM) 5-fold<sup>(1)</sup>.

While MetS is a growing epidemic worldwide, the prevalence reaches 25% to 50% in some urban areas of South Asia and the prevalence of individual risk factors is even greater, with obesity and low high-density lipoprotein cholesterol (HDL-cholesterol) reaching 68 and 81% respectively<sup>(2)</sup>. These risk factors are also growing in prevalence amongst children and young adults<sup>(2)</sup>.

The risk of MetS can be reduced through diet and lifestyle changes<sup>(3,4)</sup>. In particular, approaches including weight loss<sup>(4,5)</sup> increased wholegrain sources of carbohydrates<sup>(6,7)</sup>, and increased dairy intake<sup>(8)</sup> have a demonstrable effect on components of the MetS. However, the majority of studies into MetS have been carried out in older, Western populations or Southern Asians who have migrated to Western countries<sup>(4-9)</sup>.

There are differences in the presentation of MetS in Southern Asians, who are at higher risk of MetS risk factors such as increased waist circumference (WC) and hyperglycaemia at a given BMI alongside lower HDL-cholesterol and higher levels of small, dense low-density lipoprotein cholesterol (LDL-cholesterol) compared to their Caucasian counterparts<sup>(2)</sup>. Diet and lifestyle may also differ. For example, Indians consume a higher percentage of their calories as carbohydrates compared with Europeans, potentially increasing the risk of hypertriglyceridaemia<sup>(10)</sup>. Lower intakes of monounsaturated fat (MUFA), n-3 polyunsaturated fat (PUFA) and fibre, and higher intake of total fat, saturated fat, carbohydrates and trans fat have also been reported<sup>(11)</sup>.

The effect of small changes in diet on metabolic risk factors is subtle and occurs over time. Therefore, prospective studies are needed to account for confounding variables such as weight change, and longitudinal trends in dietary intake. Furthermore, it is important to note that a one-size-fits all approach may not be appropriate given the heterogeneous presentation of MetS. For example, a recent study found that a 10% increase in the consumption of rice was associated with lower weight gain, reduced risk of hypertension, but an increased risk of hyperglycaemia

<sup>(12)</sup>, indicating that diets could be tailored to the prevalent risk factors. Studies with large sample sizes are needed to examine the effect of specific nutrients on components of MetS <sup>(12-14)</sup>.

The DIABRISK-SL study <sup>(15)</sup> is a randomised controlled parallel group clinical trial performed at a single centre in Colombo, Sri-Lanka to examine the effect of a lifestyle intervention on the primary composite cardio-metabolic end points of: new onset T2DM, impaired glucose tolerance, impaired fasting glycaemia, new onset hypertension and albuminuria, following 5 years of intervention [in press]. In this paper, we explore the dietary factors which mediate the beneficial effects on the primary outcomes.

## **Method**

The design of the trial is described in full elsewhere <sup>(15)</sup>. In brief, 4683 Sri Lankan urban young males and females aged 5-40 years at high risk of MetS were randomized to intensive lifestyle modification group or less intensive control group. The representative sample was recruited following screening of 23,298 individuals aged 5-40 years in schools, workplaces, universities and community organisations across Colombo, Sri Lanka. Clinical and dietary data was collected at baseline, and annually up to the final follow-up. In this study we utilized only the data of the 2637 subjects who completed the 5-year study, and for whom full dietary data was available. All participants provided written informed consent and the study was given ethical approval from the Sri Lanka Medical Association Ethical Review Committee (ERC 07-010). Permission from the Ministry of Education was obtained for this study which was conducted under the Good Clinical Practice Guidelines and according to the principles expressed in the Declaration of Helsinki for clinical research.

## **Participants**

Inclusion criteria were aged 5-40 years with two or more of the following risk factors for cardio-metabolic disease: First degree family history of T2DM, physical inactivity, elevated BMI and raised WC. These risk factors were defined as: physical inactivity (<30 minutes continuous exercise for <3 days/week); WC: (in subjects between 5-17 years defined as  $\geq 91$ th percentile;

18-40 years: females  $\geq 80$  cm and males  $\geq 90$  cm); and raised BMI (in subjects aged 5-18 years defined as a BMI value greater than internationally standardized age and sex specific percentile cutoffs and between 18-40 years as BMI  $\geq 23$  kg/m<sup>2</sup>) <sup>(15)</sup>. Exclusion criteria were subjects with no or only one identifiable risk factor; subjects with diagnosed end-points (T2DM, cardiovascular disease (CVD), hypertension and renal disease) or subjects on any form of medication used for the treatment of diabetes, hypertension, renal disease or dyslipidaemia either at screening or during the study. Subjects were also excluded if they had any active communicable or non-communicable disease such as cancer, asthma or other forms of chronic lung disease, depression, tuberculosis or were or became pregnant either at screening or during the study.

### **Intensive versus Control Group**

Subjects were randomized to an intensive lifestyle intervention group in which they had three monthly telephone and/or face-to-face contacts to assess progress and reiterate goals. The total number of one-to-one contacts was 4 per year. In the control group, the same advice was given, but with the face-to-face contacts being annual. For the purposes of this analysis, the intervention and control groups were combined.

### **Dietary Goals**

Overall, lifestyle advice was based on the Indian Diabetes Prevention Program <sup>(16)</sup> namely 1) Individual advice to balance food intake and physical activity and to achieve or maintain appropriate body weight. 2) Avoidance of simple sugars and refined carbohydrates. 3) Reduce total fat intake (not to exceed 20 g/day). Restrict use of saturated fat. 4) Include more fibre-rich food – whole grains, legumes, vegetables and fruits <sup>(16)</sup>. The advice was based on the needs of the subjects. For example, in adults with a raised BMI or WC advice was given to achieve a 5% weight loss. For children, the aim was to limit weight gain. Subjects were also advised on the importance of regular meals and to avoid delaying or missing meals.

Details on physical activity are described in full elsewhere <sup>(12)</sup>.



In order to standardize both the provision of dietary advice and collection of dietary data, an exchange system was designed to replace energy-dense, high-fat, refined foods (unrecommended items) with low-energy dense, fibre-rich food sources (recommended items) (Supplementary data) to correspond with the four dietary aims. With the use of the exchange model, participants were guided towards replacing the non-recommended with recommended items. While the advice given was individualized, largely the focus was on replacing polished starches with unpolished, starchy vegetables with-non starch vegetables, high-fat meats and dairy with low-fat meats and dairy and reducing consumption of sugar-sweetened beverages.

A food frequency questionnaire (FFQ) was then adapted from the exchange model to determine the number of servings of each food group to allow annual dietary data collection. Serving sizes used were rice serving spoons and tablespoons and the food recall was completed by a trained peer-to-peer educator with the participant. This exchange model approach was used as it facilitated the provision of effective dietary advice across a population by non-medically or nutritionally trained individuals from local communities, and would therefore be straightforward to translate to similar settings.

The intervention also addressed meal timing such as reducing snacks and consuming regular meals, based around traditional Sri Lankan meals and customs. The number of meals skipped and snacks consumed per day was also recorded by the educator.

### Peer-to-Peer Educators

The intervention was delivered by peer-to-peer educators recruited from the same communities as the study participants. More than 50% of participants were  $\leq 18$  years old, and this type of community-driven intervention is an effective approach for promoting lifestyle change <sup>(17)</sup>. All educators received initial and ongoing training by a team of local and international educators, assessed by the International Diabetes Federation, and supervised by academics from King's College London. A training manual was provided, and during weekly meetings throughout the study period cases were discussed and agreed, and each educator was required to make a weekly presentation on a relevant topic to the principal investigator and head of research. This ensured correct advice was being imparted to the participants.

## Outcomes

The clinical outcomes are defined in a description of the trial published elsewhere <sup>(15)</sup>. In brief, metabolic syndrome was defined by the International Diabetes Federation <sup>(14)</sup>. At baseline and each year of the trial (Y1, Y2, Y3 and Y4), the following outcomes were measured: weight, WC, BMI, fasting plasma glucose (FPG), fasting triglycerides (TG), fasting HDL-cholesterol and LDL-cholesterol and blood pressure. At Y3, but not the Y4 final visit, an OGTT was performed. For changes in 2-hour plasma glucose (2hPG) as the dependent variable, all other variables entered in the regression equation were also taken from Y3. Physical activity was measured by the International physical activity questionnaire (IPAQ), and dietary intake was self-reported using the culturally appropriate food FFQ.

## Statistics

Exploratory analysis using correlations, independent t-tests and one-way ANOVAS was carried out to determine variables of interest and inform the regression analyses. Multiple regression analysis was performed to examine the effect of the independent variable of dietary factors on the dependent variables of change in clinical outcomes from baseline to Y4. Since the primary advice was to replace non-recommended items with recommended food items, for the independent variables, we created ratios of total recommended items:non-recommended items each year of data collection, which were averaged from baseline to the final Y4 follow-up. We also created ratios of unpolished:polished rice, and low-fat: high-fat food items which were also averaged over 5 years to account for any changes in diet over the course of the study. We also created a variable for total unpolished:polished starches to include bread, and all associations were the same as for unpolished:polished rice so data are not presented here. In addition, based on current literature on dairy (total, low-fat only and full-fat only) <sup>(8)</sup> and soluble fibres (dahl and pulses) <sup>(18)</sup> we also created two groups for these, again averaged over the study period. We also created averages of weekly intake of specific food groups over the 5 years study period, again based on existing literature, namely red meat <sup>(9)</sup>, sugar sweetened beverages <sup>(19)</sup> and processed meat<sup>(20)</sup>. The dependent variables were the change from baseline to Y4 follow-up in FPG, HDL-

cholesterol, LDL-cholesterol, TG, WC, blood pressure and weight. Regression with change in weight and WC as outcomes of interest included baseline BMI, the baseline value for dependent variable of interest, gender, age, ethnicity, alcohol intake, smoking and physical activity (total METs per week averaged over 5 years), and the two major dietary components: unpolished: unpolished rice and non-fat: high fat food products. The regression model for all other outcome variables were additionally adjusted for change in body weight. An oral glucose tolerance test was performed at Y3, not Y4, so the effect of dietary variables on 2hPG were assessed using ratio/food group intake and physical activity averaged over 4 years, and weight change up to 4 years, instead of 5. Normality tests were performed for all dependent variables and non-normal variables were transformed prior to analysis, and data were checked for homoscedasticity and collinearity of independent variables. Dummy variables were created for categorical independent variables. Standardised  $\beta$  values are reported to enable comparison of dietary factors on clinical outcomes. Statistical analyses were performed using the SPSS statistical software for Windows, version 14.0 (SPSS, Chicago, IL). A p-value of  $<0.05$  was considered as significant.

## **Results**

### **Study Participants**

Baseline demographic characteristics and food intake data for all participants for whom complete dietary data are available (n=2637) are shown in table 1 separated by age ( $>$  or  $<$  than 18 years).

### **Weight and Waist Change**

All food patterns were significantly related to weight change when examined by t-test. Participants who ate meals outside the home ( $P<0.0001$ ), did not have regular meals ( $P<0.0001$ ), skipped breakfast ( $P<0.0001$ ), lunch ( $P<0.001$ ), or dinner ( $P<0.001$ ), and had  $\geq 1$  snacks per day ( $P<0.0001$ ), had significantly higher weight gain at the Y4 follow-up. WC at Y4 was also significantly higher in those who ate meals outside the home ( $P<0.0001$ ), those who did not eat regular meals ( $P<0.001$ ), those who skipped breakfast ( $P<0.0001$ ) and those who had  $\geq 1$  snacks per day ( $P<0.001$ ) (Figure 1). However, when controlled for age, gender, BMI, physical activity,

alcohol intake, baseline weight or WC, only having regular meals was significantly related to weight change ( $\beta=-0.037$ ,  $P=0.032$ ) and WC ( $\beta=-0.038$ ,  $P=0.011$ ).

There was no effect of any food or food group on weight change, WC at the Y4 follow-up after controlling for confounders.

## **Biochemical Outcomes**

### **FPG**

The ratio of total recommended: non-recommended items ( $\beta=-0.049$ ,  $P=0.023$ ) and unpolished:polished rice ( $\beta=-0.084$ ,  $P=0.007$ ) was inversely related to change in FPG at Y4 after controlling for age, gender, BMI, physical activity, alcohol intake, baseline FPG and weight change (Table 2) (Figure 2a). Red meat was also positively related to FPG ( $\beta=0.05$ ,  $P=0.017$ ), but processed meat as a separate category was not. Not having regular meals was also associated with a higher FPG at the Y4 follow-up ( $\beta=0.049$ ,  $P=0.01$ ) (Table 2).

### **2hPG**

The total amount of recommended:non-recommended food items was not related to 2hPG at Y4, nor was unpolished:polished rice, low-fat:high-fat . However low-fat dairy ( $\beta=-0.046$ ,  $P=0.018$ ) but not total or high-fat dairy ( $\beta=0.003$ ,  $P=0.853$ ;  $\beta=-0.010$ ,  $P=0.601$ ) was inversely related to 2hPG at the Y4 follow-up (Table 2). Physical activity was also negatively related to 2hPG (Table 2).

### **HDL-Cholesterol**

The ratio of total recommended: non recommended items ( $\beta=0.044$ ,  $P=0.032$ ) and unpolished:polished rice ( $\beta=0.066$ ,  $P=0.031$ ) was positively related to HDL-cholesterol concentration (Table 3) (Figure 2b). There was no relationship between any other dietary variables including seafood, pulses or meal patterns and HDL-cholesterol concentrations.

## **TGs**

The ratio of unpolished:polished rice ( $\beta=-0.084$ ,  $P=0.005$ ), white fish intake ( $\beta=-0.059$ ,  $P=0.003$ ) and soluble fibre intake ( $\beta=-0.044$ ,  $P=0.025$ ) were also negatively related to TG concentrations (Table 3).

## **Blood Pressure**

After adjusting for age, gender, BMI, physical activity, alcohol intake, baseline blood pressure, there was no relationship between meal timings and blood pressure. Total dairy demonstrated a borderline association with diastolic ( $\beta=-0.031$ ,  $P=0.052$ ) blood pressure. When low-fat dairy was analysed separately, the relationship was significant ( $\beta=-0.046$ ,  $P=0.004$ ). There was no relationship between any other dietary variable including fruits and vegetables, low-fat products in general and unpolished:polished rice and blood pressure.

## **Total and LDL-Cholesterol**

There was no relationship between any dietary variable and total or LDL cholesterol.

## **Relationship between Meal Timings and Food Group Intake**

Participants who skipped meals had significantly lower ratio of recommended: non recommended food items ( $P<0.001$ ); low:high fat products ( $P<0.0001$ ) and unpolished:polished rice ( $P<0.0001$ ) than those who did not skip meals. Participants who snacked had lower ratio of recommended:non recommended food items ( $P<0.0001$ ) and low:fat products ( $P<0.0001$ ). Participants who ate meals out of the home had lower ratio of recommended:non recommended food items ( $P<0.0001$ ) and unpolished:polished rice ( $P<0.0001$ ).

## Discussion

In this 5-year interventional trial in a young population at high risk of CVD, it has been shown that replacing white rice with unpolished rice may be a particularly effective individual dietary change to reduce risk factors for T2DM and CVD. Other foods and food groups which appear to exert their risk reduction effects via specific metabolic risk factors are also highlighted.

White rice consumption has been linked to T2DM risk in several cohort studies <sup>(21,22)</sup>, and the relative risk is not only higher in Southern Asians per serving <sup>(22)</sup>, Southern Asians consume more white rice than their Western counterparts <sup>(11,23)</sup>. Rice immediately harvested comprises the bran, germ, and endosperm. White – or polished – rice is produced by milling which removes the hull, bran (primarily non-cellulosic polysaccharides, cellulose and lignin) and most of the wheatgerm <sup>(24)</sup>. Unpolished rice retains beneficial fatty acids including oleic and linoleic acid <sup>(24)</sup>, protein, bran and some vitamins <sup>(24)</sup> and is higher in fibre and has a lower glycaemic index than white rice <sup>(23,24)</sup>.

Total dietary fibre, cereal fibre and low glycaemic index foods have been repeatedly linked to improved glycaemic control and lower risk of T2DM in a variety of studies <sup>(25-29)</sup>. In general, wholegrain, cereal or insoluble fibres are associated with lower T2DM risk in cohort studies <sup>(28)</sup>, whereas soluble fibres reduce postprandial glucose concentrations in the controlled setting <sup>(28)</sup>. Our data suggest that sources of wholegrain fibre (mainly insoluble) may exert their T2DM preventive effects by specifically altering fasting glucose concentrations, as the association was strong and not altered by adjusting for multiple confounders, and no association was found between unpolished rice or starches on 2hPG concentrations in any model. There is limited epidemiological data on this question as the majority of cohort studies use T2DM incidence as the dependent variable, not FPG or 2hPG concentrations <sup>(25,26,29)</sup>, but controlled trials and cohort studies that measure FPG and 2hPG with appropriate adjustment have shown a reduction in fasting but not post-prandial glucose <sup>(30-32)</sup>. Fasting glucose concentrations are rising at a rate of 0.07mmol/L per decade across the population <sup>(33)</sup>. Our finding that replacement of white rice with unpolished rice significantly reduces FPG has important public health implications in countries such as Sri Lanka where rice is a staple food.

Dietary fibre has also been linked to reduced weight and WC in a number of cohort and controlled studies <sup>(34-36)</sup>, with the mechanism posited to be by a bulking effect, lowering energy density and/or the glycaemic index of the diet <sup>(28)</sup>. Products of dietary fibre fermentation have also been shown to increase the production of hormones which decrease appetite <sup>(27,33,35)</sup>. For example, inulin supplementation attenuates weight gain in overweight children over one year <sup>(34)</sup>. While it has been thought that soluble fibres are generally fermentable, while insoluble fibres are not <sup>(28)</sup>, other authors have shown that long-term, cereal fibres such as cellulose are fermented and associated with increases in GLP-1 and a reduction in appetite <sup>(37)</sup>. Since our regression models were adjusted for changes in weight, our data therefore suggest that substitution of white rice with unpolished rice has a two-pronged effect on T2DM risk, firstly by limiting weight gain, and secondly by its independent effects on FPG.

No effect was observed by replacing total high-fat food items with their low-fat varieties on any of the outcome measures studied. The role of fat in risk of T2DM and CVD is complex, with different fat sources, classes and separate fatty acids possibly having distinct and opposing effects on T2DM risk <sup>(38)</sup>. Dairy fat in particular has been linked to a reduction in risk <sup>(8,38)</sup>, although our finding that low-fat but not total dairy was associated with a reduction in 2hPG suggests that the erstwhile nutrients of dairy products such as calcium, and milk proteins may be mediating this beneficial effect <sup>(39)</sup>.

An association between red meat and FPG was found, but not with 2hPG. This is supported by previous cohort studies <sup>(19)</sup>, with data also suggesting that red meat intake is specifically associated with fasting glucose and risk of impaired fasting glucose <sup>(40,41)</sup>. While no association between processed meats and any outcome was found, in contrast to a body of work implicating processed meat in coronary heart disease and T2DM<sup>(42)</sup> this may reflect the limited consumption of such foods in the Sri Lankan diet.

The lipid profile is an important component in the development of CVD, and Southern Asians have lower HDL-cholesterol compared to their Caucasian counterparts <sup>(2)</sup>. While the relationship between wholegrains, glucose concentrations and TG levels are well documented <sup>(28)</sup> there is little suggestion in the literature that dietary fibre influences HDL-cholesterol concentrations. In the current study, replacing white rice with unpolished rice was associated with increases in HDL-cholesterol, and the relationship remained significant after adjusting for multiple factors,

including factors known to alter HDL-cholesterol such as alcohol, smoking and physical activity. Interestingly, both consumption of white rice and glycaemic load of the diet negatively associate with HDL-cholesterol across a number of populations <sup>(43,44)</sup>. Therefore, it appears that while adding wholegrain to the diet is important for glycaemic control, weight management and reduction of TG, its displacement of high glycaemic index, highly-refined rice is equally important for the benefit on HDL-cholesterol.

There is a growing body of data demonstrating the importance of meal timings on CVD risk factors <sup>(13,14)</sup>. Although our finding that regular meals were negatively associated with weight and WC is limited by the lack of control for energy intake, it is supported by data from large cross-sectional studies in the UK <sup>(13)</sup> and Sweden <sup>(14)</sup>, and by prospective studies in children <sup>(45)</sup> and adults <sup>(46)</sup>. After controlling for weight change, irregular meals was also positively associated with FPG, which may be due to the effect of irregular meals on circadian secretion of hormones including GLP-1 and insulin <sup>(46)</sup>. Advice to consume regular meals was easy to translate across this population and could be tested independently in a controlled setting.

Some interesting associations between dietary factors and specific components of the metabolic syndrome were observed. It is now clear that the prediabetic period is characterised by two separate conditions: impaired fasting glucose, and impaired glucose tolerance, each with its own distinct underlying pathophysiology <sup>(47)</sup>. Our findings highlight the distinct roles nutrients and meal patterning may play in the development of T2DM, and suggest that regular meals, a reduction in red meat and increased bran intake may specifically affect fasting glucose dysregulation, while physical activity and low-fat dairy may target the peripheral insulin resistance which characterizes impaired glucose tolerance <sup>(47)</sup>.

Some strengths of this study while acknowledging its limitations are highlighted. Firstly, food intake data was collected every year of this 5-year study, enabling the calculation of average intake over time, and the reduction of within-person measurement errors <sup>(23)</sup>. The long-follow up period also enabled the examination of the effect on clinical factors overtime. However, because the FFQ - which themselves have limitations - was adapted to the target population, it has not been validated. While portion sizes were indicated by the participants with the use of serving spoons, this method could have introduced error. The analyses cannot therefore be reliably adjusted for energy intake. Nevertheless, the primary findings of this study have been controlled



for weight change over 5 years, which is arguably a more reliable estimate of energy intake and energy balance. In Sri Lankan cuisine soy, sunflower, palm and coconut oils are used for cooking and have known effects on CVD risk factors <sup>(48,49)</sup>. Although fried foods were controlled for in our analyses, the FFQ did not include collection of data for the different dietary oils or fats used in cooking and it is possible that differences in these sources mediated the relationships seen. This is particularly relevant as coconut oil is commonly consumed as an added factor in Sri Lanka, and is implicated in both promoting or limiting CVD progression <sup>(50,51)</sup>. We acknowledge our exchange model included some foods such as egg yolks and nuts in the non-recommended category even they are thought to have neutral or beneficial effects on T2DM or CVD risk in most people. However, its primary design was to reduce the energy density of the diet in a way that was simple to understand and translate for community-recruited educators who did not have a background in nutrition. Finally, these analyses used pooled data from the intervention and control group of a primary prevention trial. Thus, while the original study was controlled, this current analysis cannot infer causation.

In conclusion, a pragmatic dietary intervention can significantly reduce risk factors for MetS in a high-risk population. Replacement of white with unpolished rice may be particularly effective dietary advice in this and similar populations.

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#### Conflict of Interest

The authors declare no conflict of interest.

#### Authorship

JK, GV, LG and MW conceived the study and its design, were involved in implementation of the study. NG led the dietary analysis plan, carried out all data analysis, and wrote the manuscript with feedback from the other authors. LV, JK MG, GV, LG and MW were involved in coordination of the study.

All authors read and approved the final manuscript. NG is the guarantor of this work and, as such, had full access to all the data in the study and takes responsibility for the integrity of the data and the accuracy of the data analysis.

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Figure 1: Changes in weight (a) and waist circumference (b) at 5 years by whether or not meals are eaten out of the home (external meals), whether 3 regular meals are eaten per day (regular meals), whether breakfast, lunch or dinner are delayed or skipped (skip b/fast, skip lunch, skip dinner) and whether  $\geq 1$  snacks are consumed per day (Snacks). Differences determined by independent t-test. Values are means, with their standard errors represented by vertical bars.

External: external meals; Regular: regular meals; B: Breakfast; L: Lunch; D: Dinner; Snacks: regular snacks. N: No; WC: waist circumference; Y: Yes. \*=p<0.05, \*\*=p<0.01, \*\*\*=p<0.001, \*\*\*\*=p<0.0001

Figure 2: Change in fasting plasma glucose (a) and HDL-cholesterol (b) for participants consuming a ratio of recommended:non-recommended items and a ratio of unpolished:polished rice of more or less than 1. Differences determined by independent t-test. Values are means, with their standard errors represented by vertical bars. FPG: Fasting plasma glucose; HDL-cholesterol: high-density lipoprotein cholesterol; Rec: recommended.  $\ast = p < 0.05$ ,  $\ast\ast = p < 0.01$ ,  $\ast\ast\ast = p < 0.001$ ,  $\ast\ast\ast\ast = p < 0.0001$





Demographic Characteristics				
	Under 18 years (N=1250)		Over 18 years (N=1387)	
	Mean	SD	Mean	SD
Age (years)	13.1	2.1	30.9	6.2
Gender (M:F) (%)	41: 59		54:46	
Waist (cm)	79.2	11.0	87.7	9.5
Weight (kg)	55.2	13.6	67.0	12.5
BMI (kg/m <sup>2</sup> )	22.5	4.2	25.1	3.7
FPG (mg/dL)	88.2	6.6	89.9	9.1
2hPG (mg/dL)	103.7	19.6	108.5	30.0
TC (mg/dL)	179.4	29.0	199.0	32.6
LDL-cholesterol (mg/dL)	133.5	26.4	132.1	30.0
HDL-cholesterol (mg/dL)	46.0	10.7	42.9	9.6
TGs (mg/dL)	99.3	47.9	118.7	58.8
Food group Servings per week	Median	IQR	Median	IQR
Brown rice	6	14	6	14
Pulses	1	2	0	1
White rice	7	14	7	14
White bread	2	7	1	3
Wheat flour products	0	1	0	1
Green leafy vegetables	7	4	6	4
Starchy vegetables	1	2	1	3
Fruity vegetables	14	7	21	7
Dhal	7	4	7	4
Sweet fruit	7	4	4	5
Dates, plums, prunes	0	0	5	0
Whole milk	7	7	7	11
Whole milk products	1	3	0	2
Fresh fish	7	4	7	3

Chicken	1	2	1	2
Processed meat	0	2	0	0
Egg white	2	2	2	2
Egg yolk	2	2	1	2
Crisps/chips	0	3	0	2
Fried rice	0	1	0	2
Sweetened tea/coffee	3	7	7	14
Ice cream	0	1	0	1
Biscuits	7	7	2	7
Sweetened fruit juice	0	2	0	0

Table 1: Baseline demographic characteristics and food intake data. Data are mean and standard deviation (SD) for demographic variables; and median and interquartile range (IQR) for food intake data which were not normally distributed. Where median and IQR are <1 serving per week, data is not shown. BMI: Body Mass Index; TC: Total cholesterol; FPG: fasting plasma glucose; HDL-cholesterol: high-density lipoprotein cholesterol; LDL-cholesterol: low-density lipoprotein cholesterol; TGs: triglycerides; 2hPG: 2-hour plasma glucose.

	FPG		2hPG	
	$\beta$ -coefficient	P value	$\beta$ -coefficient	P value
Recommended:non-recommended	-0.049	0.023	-0.001	0.96
Unpolished:polished	-0.084	0.007	0.034	0.20
Soluble fibre	-0.003	0.91	0.009	0.63
Red meat	0.050	0.018	0.001	0.961
Low:fat dairy	-0.032	0.13	-0.046,	0.018
Regular meals	-0.049,	0.01	0.014	0.46
Alcohol	-0.041	0.029	-0.042	0.02
Physical activity (mets)	-0.005	0.77	-0.037	0.038

Table 2:  $\beta$ -coefficients for the effect of food patterns, groups and specific foods on FPG and 2hPG. FPG: Fasting plasma glucose. 2hPG: 2-hour plasma glucose.

	HDL-cholesterol		TG	
	$\beta$ -coefficient	P value	$\beta$ -coefficient	P value
Recommended:non-recommended	0.044	0.032	-0.018	0.33
Unpolished:polished	0.066	0.031	-0.084	0.005
Soluble fibre	0.28	0.16	-0.044,	0.025
Red meat	-0.009	0.65	0.034	0.083
Low:fat dairy	-0.019	0.33	0.001	0.97
White fish	0.037	0.06	-0.059	0.003
Regular meals	0.019	0.30	0.009	0.61
Alcohol	0.035	0.06	-0.025	0.21
Physical Activity	-0.008	0.65	-0.025	0.15

Table 3:  $\beta$ -coefficients for the effect of the ratio of unpolished rice: white rice on clinical and biochemical outcomes. HDL-cholesterol: high-density lipoprotein cholesterol.

